



Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies



August 3, 2005
Loews L'Enfant Plaza Hotel
Washington, DC

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Reference: D0286

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- 1 Purpose of Study
- 2 The NG/Diesel 2010 Technology Cost Model
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There is significant uncertainty regarding the costs of natural gas and diesel heavy-duty vehicles in the future

- Today's natural gas vehicles (NGVs) are more expensive than diesel due to low volume production and high costs of on-board storage
- Heavy-duty diesel vehicles with advanced emission control technology necessary for meeting 2010 standards will be more expensive to own and operate
- Future heavy-duty NGVs meeting 2010 emission standards will also be more expensive than today's NGVs, but possibly less expensive than 2010 diesel technologies
- In order to better understand the costs of these vehicles, the California Natural Gas Vehicle Partnership commissioned a study supported by South Coast AQMD and Southern California Gas Co. to analyze the costs of several types of heavy-duty vehicles



TIAX estimated initial owner life cycle costs (LCCs) for three types of vehicles using 2010 diesel and natural gas technologies



Refuse Hauler



Transit Bus



Class 7/8 Short Haul Truck

- TIAX compared costs for 2010 technology in the following applications
 - Liquefied natural gas (LNG) refuse hauler
 - Compressed natural gas (CNG) transit bus
 - LNG class 7/8 short haul truck
- We also analyzed the sensitivity of parameters such as fuel prices, vehicle costs, and engine efficiency

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Life cycle costs (LCCs) are derived from industry average values for the U.S.

- The life cycle cost model considers the following costs:
 - Amortized vehicle capital costs over the first-owner lifetime
 - Chassis cost
 - Engine cost
 - Aftertreatment system cost
 - Fuel system cost
 - Calculated vehicle residual value at the end of first-owner lifetime
 - Net Present Value (NPV) of future costs are found in 2005 dollars
 - operation & maintenance costs
 - fuel costs
 - aftertreatment reductant costs (if any)
 - component replacement costs (if any)
- Amortized capital cost and NPV of future costs are added together and divided by the vehicle life to find the Average Annual Cost (AAC)
- The model uses expected industry average values to determine results



Resources that were used for industry average values looked at the longer term price projections of mature 2010 technologies

- Vehicle assumptions for mature 2010-technologies are from 3 main sources:
 - “California Strategies to Reduce Petroleum Dependency (AB2076)”
 - Attachment B report, Task 3 “Staff Reports on Petroleum Reduction Options”
 - Sponsored by California Energy Commission (CEC)
 - “Technology Roadmap for the 21st Century Truck Program”
 - Sponsored by U.S. Department of Energy (DOE)
 - “The Future of Heavy-Duty Powertrains”
 - TIAX and Global Insights, Inc.’s recently released study



Vehicle, engine, and application cost assumptions are identified in the table below

	Refuse Hauler	Transit Bus	Short Haul
Engine rating (hp)	325	285	470
VMT (mi/yr.)	24,855	46,603	55,923
First Owner Life (yrs.)	6.5	12	10
Fuel Economy (mpg)	3.3	3.2	4.3
FE % variation*	+/-5.1%	+/-2.8%	+/-2.3%
Annual Maintenance	\$25,833	\$39,733	\$27,404
Base Vehicle Costs			
Chassis	\$115,882	\$239,374	\$132,476
Engine	\$50/kW	\$50/kW	\$50/kW
Fuel System Cost			
Diesel	\$150	\$150	\$150
Natural Gas	\$9,000	\$12,000	\$9,500

- Maintenance costs are assumed to be the same for the diesel and natural gas vehicles
 - Diesel PM aftertreatment service costs are offset by the spark plug and fuel system maintenance costs



* the variation shown is due to technology differences and not drive cycle related

Engine fuel efficiencies assumptions were made from the technology sources and input into the financial model

- Diesel engine fuel economies for the different applications were found through GT-Drive® modeling for the “The Future of Heavy-Duty Powertrains” study
 - Fuel economies for each applications were modeled over representative drive cycles under both loaded and unloaded conditions
 - Fuel economy (FE) variation is reflective of different 2010 diesel engine technologies and not drive cycle changes
 - Fuel economy numbers from the “The Future of Heavy-Duty Powertrains” were checked against the values in the “Technology Roadmap for the 21st Century Truck Program”
- Stoichiometric natural gas engines were assumed to have 95% of the fuel economy of the equivalent (in power rating) diesel engine
 - Based on the “California Strategies to Reduce Petroleum Dependency (AB2076)”
 - Two natural gas engine manufactures have concurred with this number in their future fuel economy projections
- Aftertreatment FE penalty is calculated after base engine FE’s are found



The model assumes various engine costs for different technologies and applications

- \$50/kW is base case compression ignition direct injection (CIDI) diesel engine assumption
- Diesel engine cost variation was taken from “The Future of Heavy-Duty Powertrains” study, including homogeneous charge compression ignition (HCCI) diesel engines
- Natural Gas engine cost variation was found in “California Strategies to Reduce Petroleum Dependency (AB2076)” for stoichiometric natural gas engines

	Percent increase over base case engine					
	CIDI		HCCI		Stoich	
	Low	High	Low	High	Low	High
Refuse Hauler	Base Case	135%	102%	135%	125%	150%
Transit Bus		138%	102%	138%	117%	161%
Short Haul		125%	102%	125%	125%	139%



Aftertreatment options were chosen for diesel and natural gas technologies

- Options identified during “The Future of Heavy-Duty Powertrains” study

Emission Aftertreatment Options	
Diesel	
Option 1	Catalyzed PM trap, HC Selective Catalytic Reduction, Oxidation Catalyst
Option 2	Catalyzed PM trap, Urea Selective Catalytic Reduction, Oxidation Catalyst
Option 3	Catalyzed PM trap, Sulfur trap, NOx trap, Oxidation Catalyst
Option 4	Continuously regenerated PM trap, HC Selective Catalytic Reduction, Oxidation Catalyst
Option 5	Continuously regenerated PM trap, Urea Selective Catalytic Reduction, Oxidation Catalyst
Option 6	Continuously regenerated PM trap, Sulfur trap, NOx trap, Oxidation Catalyst
Option 7	4-way Catalyst (CIDI only)
Natural Gas	
3-way Cat	3-way Catalyst



Aftertreatment system cost is based on selected components and the size of the engine

- Aftertreatment costs are scaled with engine power ratings
 - Choice assigns the fuel economy penalties of 1-3%

Device	Med-heavy	Heavy	Multiplier for FE Penalty
Catalyzed particulate trap (PM)	\$ 1,300	\$ 1,500	1.01
Continuously regenerated trap (PM)	\$ 2,100	\$ 2,400	1.01
Sulfur trap (S)	\$ 1,560	\$ 1,820	1.01
HC SCR (NOx)	\$ 793	\$ 897	1.02
Urea SCR (NOx)	\$ 2,223	\$ 2,522	1.01
NOx trap (NOx)	\$ 1,300	\$ 1,430	1.02
4-way catalyst (CO, HC, PM, NOx)	\$ 2,470	\$ 2,860	1.03
3-way catalyst (CO, HC, NOx)	\$ 1,500	\$ 1,300	1.01
Low temp oxidation catalyst (CO, HC)	\$ 1,500	\$ 1,300	1.00
Oxidation catalyst (CO, HC)	\$ 540	\$ 610	1.00



Economy of scale factors are given to account for the limited production volume that could occur in the NGV market

- Economy of scale factors are applied to the engine, aftertreatment device, and fuel system capital costs
- NG vehicle percentage applies to vehicles produced in segment
- Assume base case of 12.5% for transit bus and refuse hauler, 5% for short haul trucks

NG Vehicle Percentage	Economy of Scale Multiplier
50%	1
12.5%	1.25
5%	1.625



Vehicle residual values are found for the end of owner life using subsystem value-lives

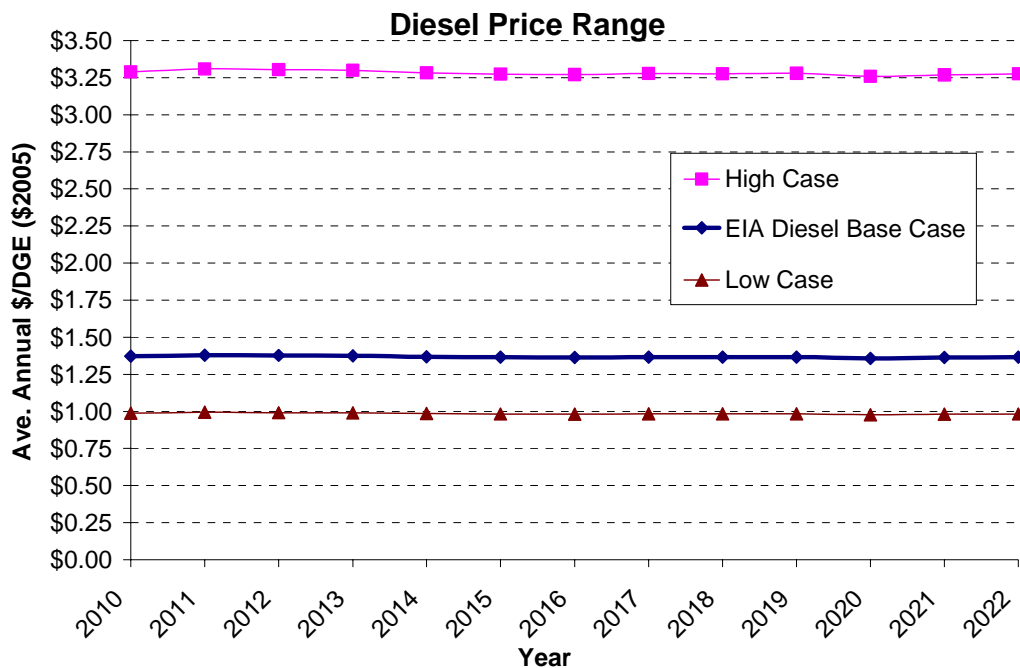
- TIAX and DBHORNE LLC estimated the value-lives for the subsystems using previous experience with life cycle cost models
- Replacement and rebuilds affect age of subsystems
- Value of subsystems are added together to find vehicle value
- Residual value = $\frac{2}{3} * (\text{age}_{\text{chassis}}/\text{value-life}_{\text{chassis}} + \text{age}_{\text{engine}}/\text{value-life}_{\text{engine}} + \text{age}_{\text{fuel system}}/\text{value-life}_{\text{fuel system}} + \text{age}_{\text{aftertreatment}}/\text{value-life}_{\text{aftertreatment}})$

Value-lives in years			
	Refuse Hauler	Transit Bus	Short Haul
Chassis	6.5	15	15
Engine	12	12	12
Aftertreatment	6.5	10	10
Fuel System	15	15	15



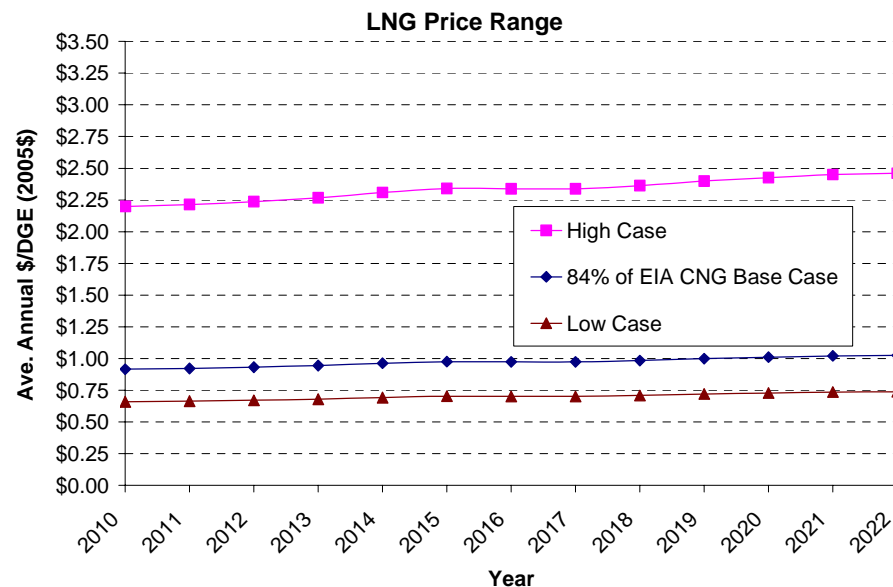
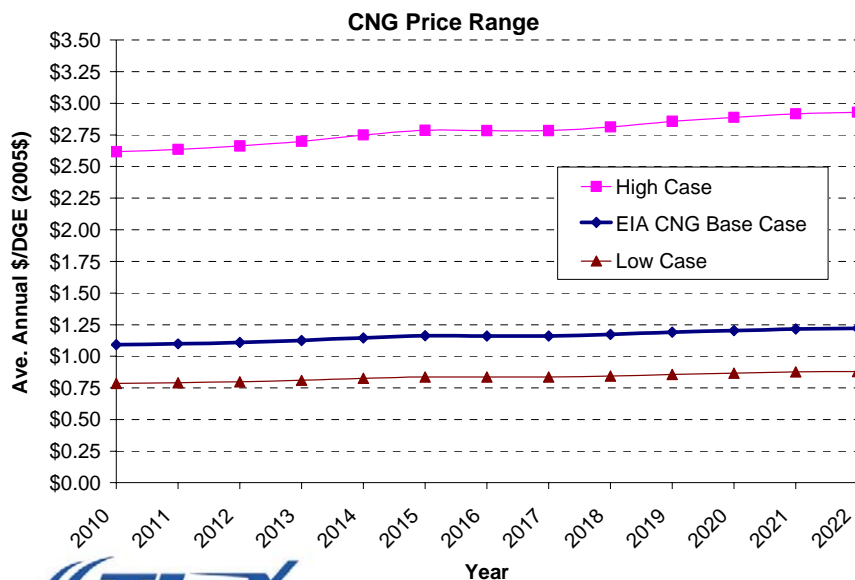
Fuel price assumptions are made to give range to an uncertain future

- Base case fuel prices are from the Energy Information Administration
 - “Annual Energy Outlook 2005”
 - National average “pump price” projections for transportation fuels includes delivery costs, infrastructure costs, and taxes
 - Base Case of \$25/bbl in 2010, increasing to >\$29/bbl in 2022
- High and low diesel prices are ratios of EIA’s base case price projections over the vehicle lifetime



Natural gas price variations are linked to the high and low diesel scenarios

- Base case fuel prices from EIA for transportation sector CNG
 - National average “pump price” projections for transportation fuels includes delivery costs, infrastructure costs, compression costs and taxes
- High and low CNG prices use the same ratios of used to project the high and low diesel cases
 - $\text{CNG}_{\text{High Case}} = \text{Diesel}_{\text{High Case}} / \text{Diesel}_{\text{Base Case}} * \text{CNG}_{\text{Base Case}}$ in each year
 - $\text{CNG}_{\text{Low Case}} = \text{Diesel}_{\text{Low Case}} / \text{Diesel}_{\text{Base Case}} * \text{CNG}_{\text{Base Case}}$ in each year
- LNG is assumed to be 84% of CNG prices for each scenario



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Major findings show comparable costs for NG and Diesel

- 2010 technology NG and diesel vehicles are highly competitive with each other on Average Annual Cost
- For each of the vehicle types, there is significant cost overlap in the range of costs for diesel and Natural Gas Vehicles (NGVs).



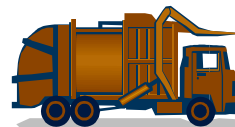
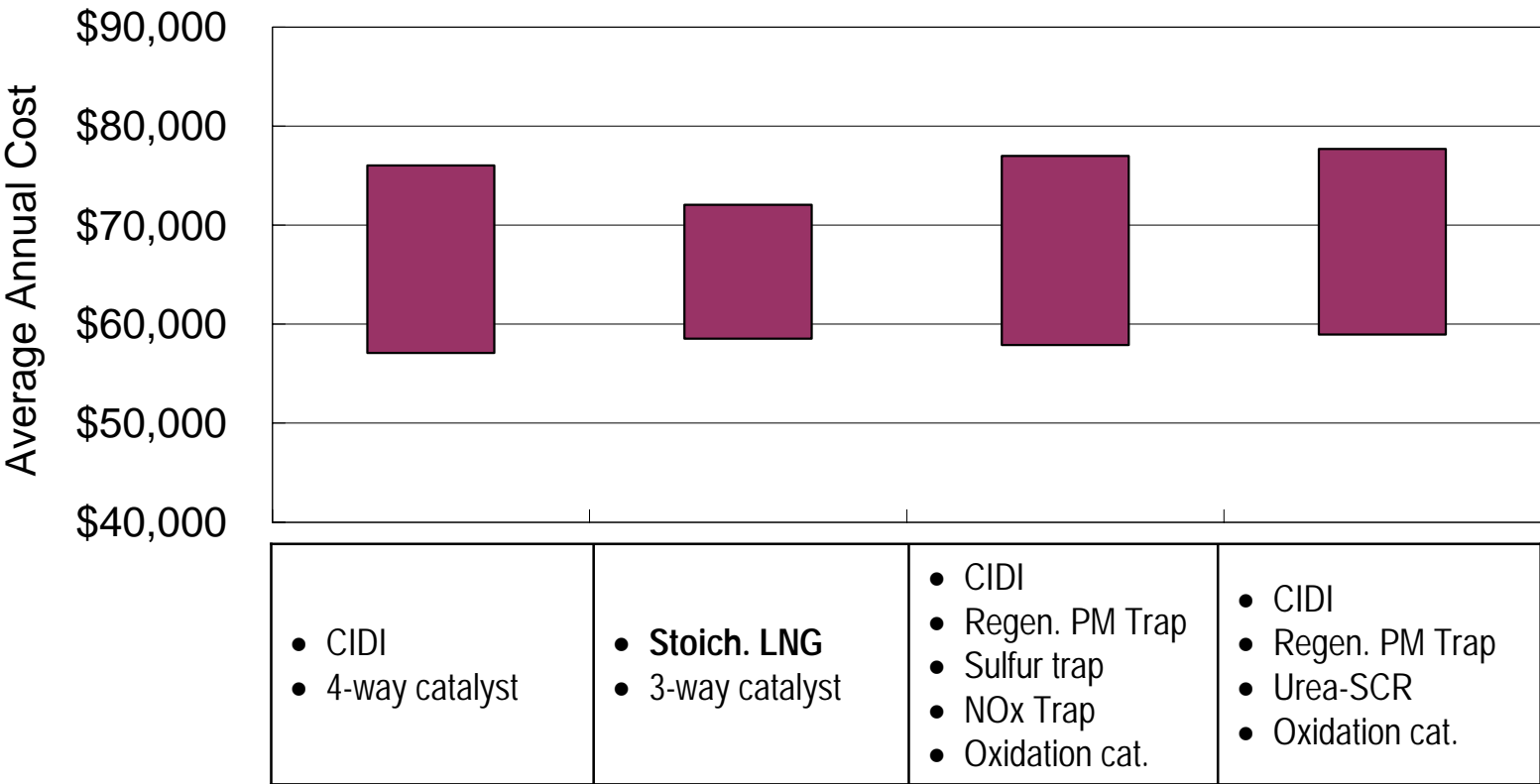
Results are shown as ranges of expected Average Annual Costs

- Range is based on expected industry-average variation of:
 - Fuel cost
 - Engine cost
 - Fuel economy

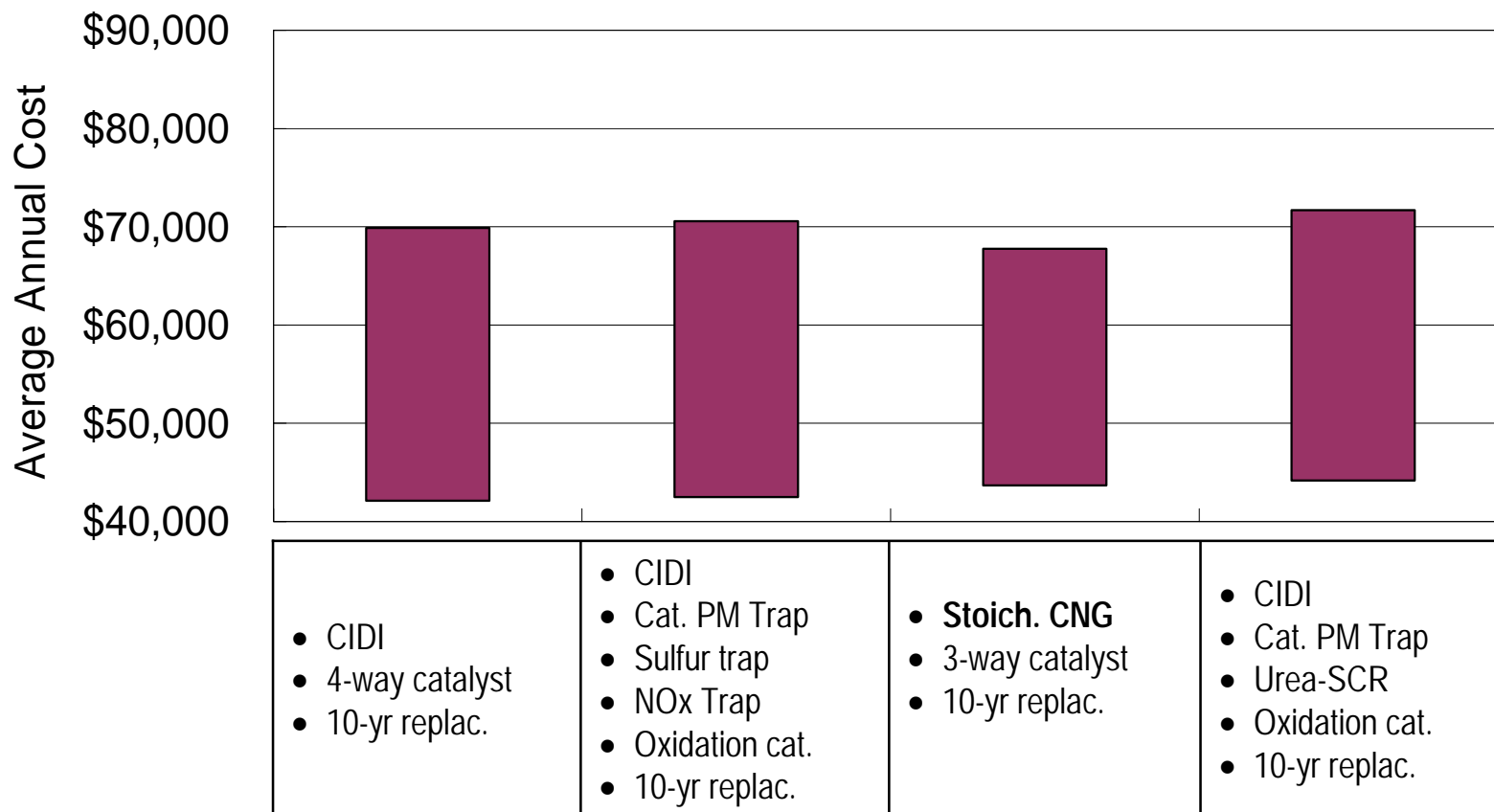
- Differences in the AAC for diesel and NGVs occurs at the extremes in the analyzed scenarios
 - Study considers coupled diesel and natural gas vehicle scenarios, high price case for both vehicles or low price case for both vehicles
 - It is assumed that:
 - High diesel prices = high natural gas prices; & low = low
 - High diesel engine prices = high natural gas engine prices; & low = low
 - Low diesel fuel economy = low natural gas fuel economy; & high = high
 - Some decoupling of the price scenarios occurs in the sensitivity analysis



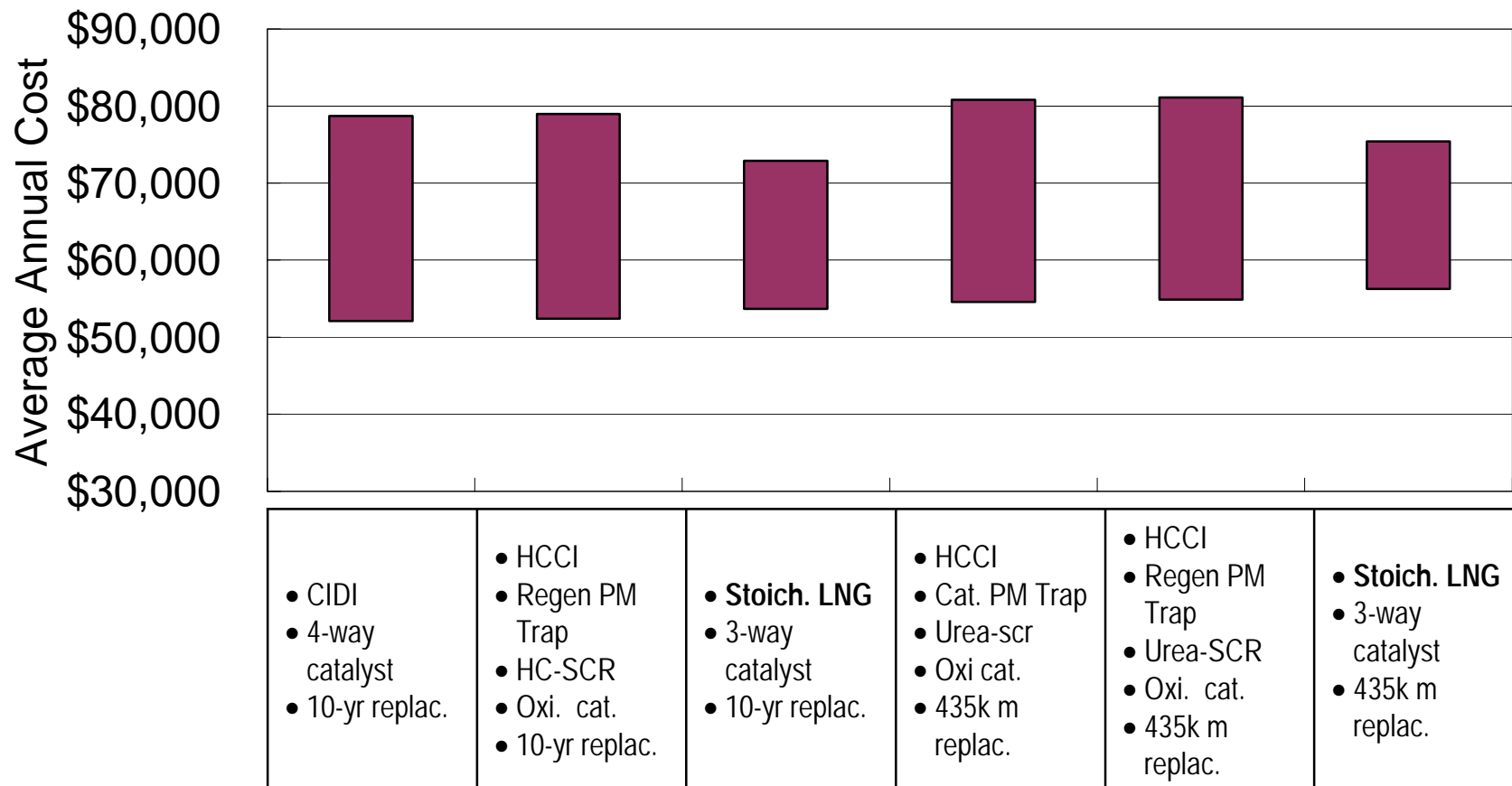
Range of Average Annual Cost for Refuse Haulers



Range of Average Annual Cost for Transit Bus



Range of Average Annual Cost for Short Haul Truck



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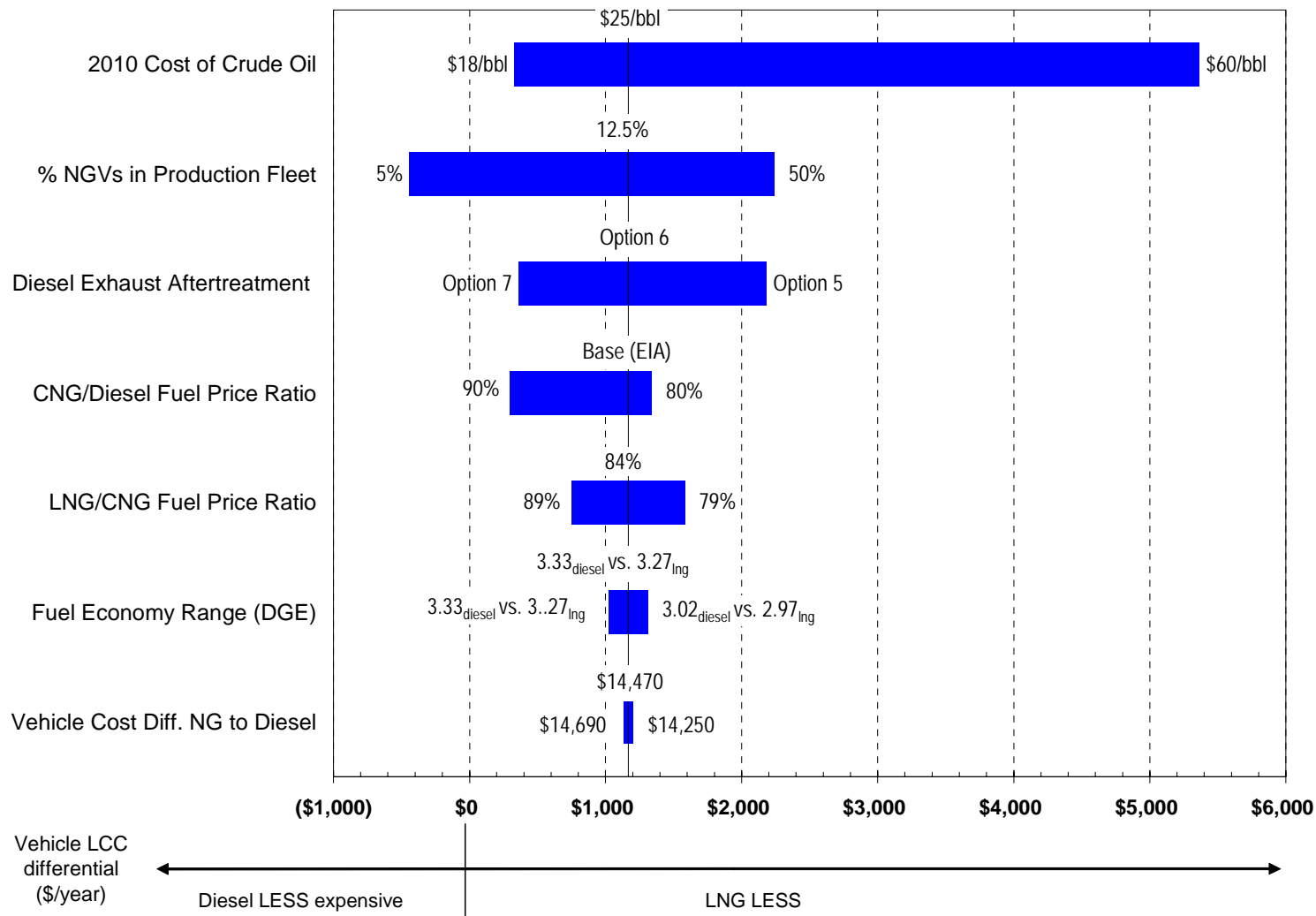
The costs are more sensitive to some variables than others

- The results are most sensitive to
 - Cost of crude oil
 - Percentage of NG vehicles in nationwide fleet
 - Incremental cost of exhaust aftertreatment
 - Price ratio between CNG and Diesel
 - Price ratio between LNG and CNG

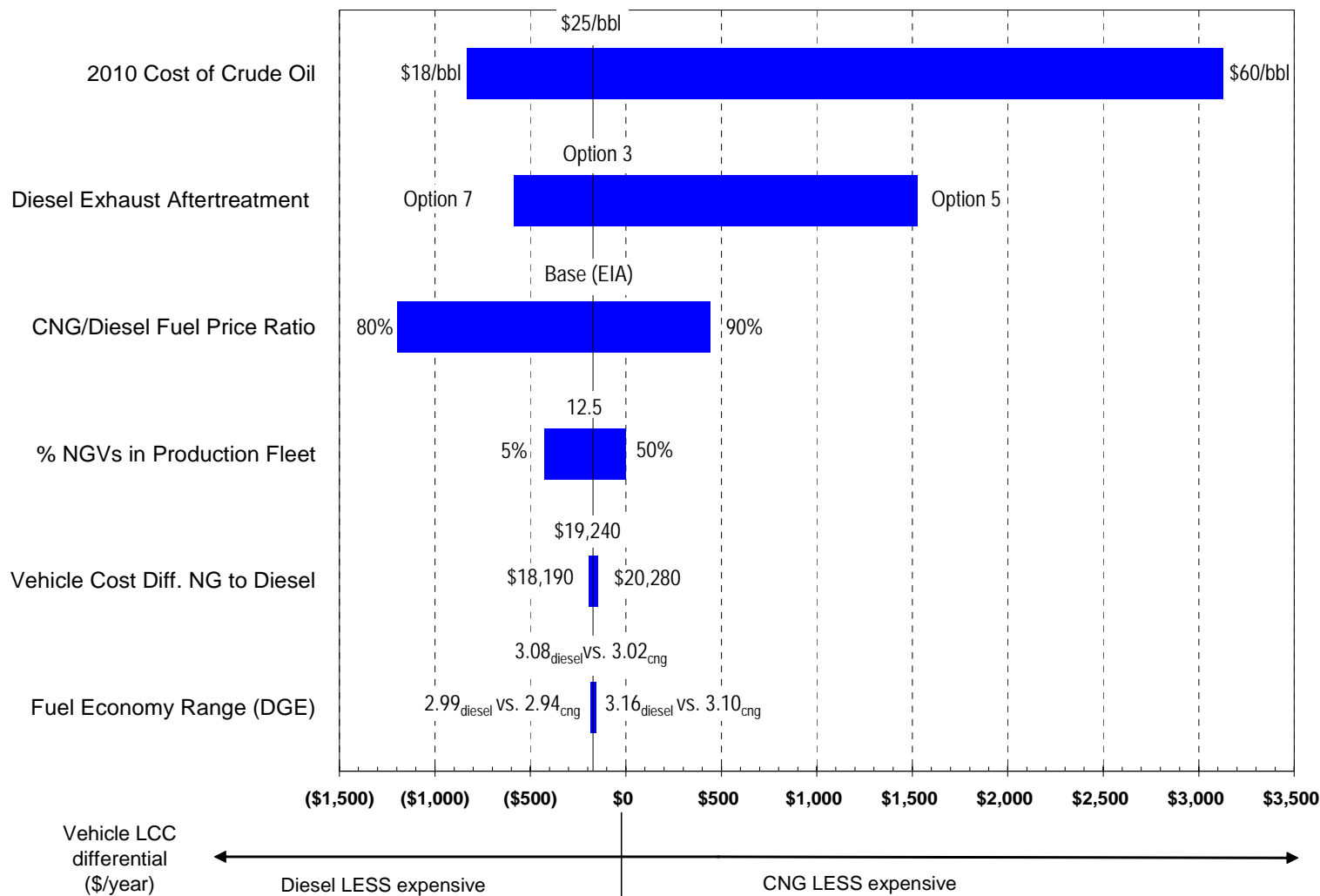
- The results are least sensitive to these variables (when varied over industry average ranges)
 - Vehicle Fuel Economy
 - Vehicle Capital Cost Differential



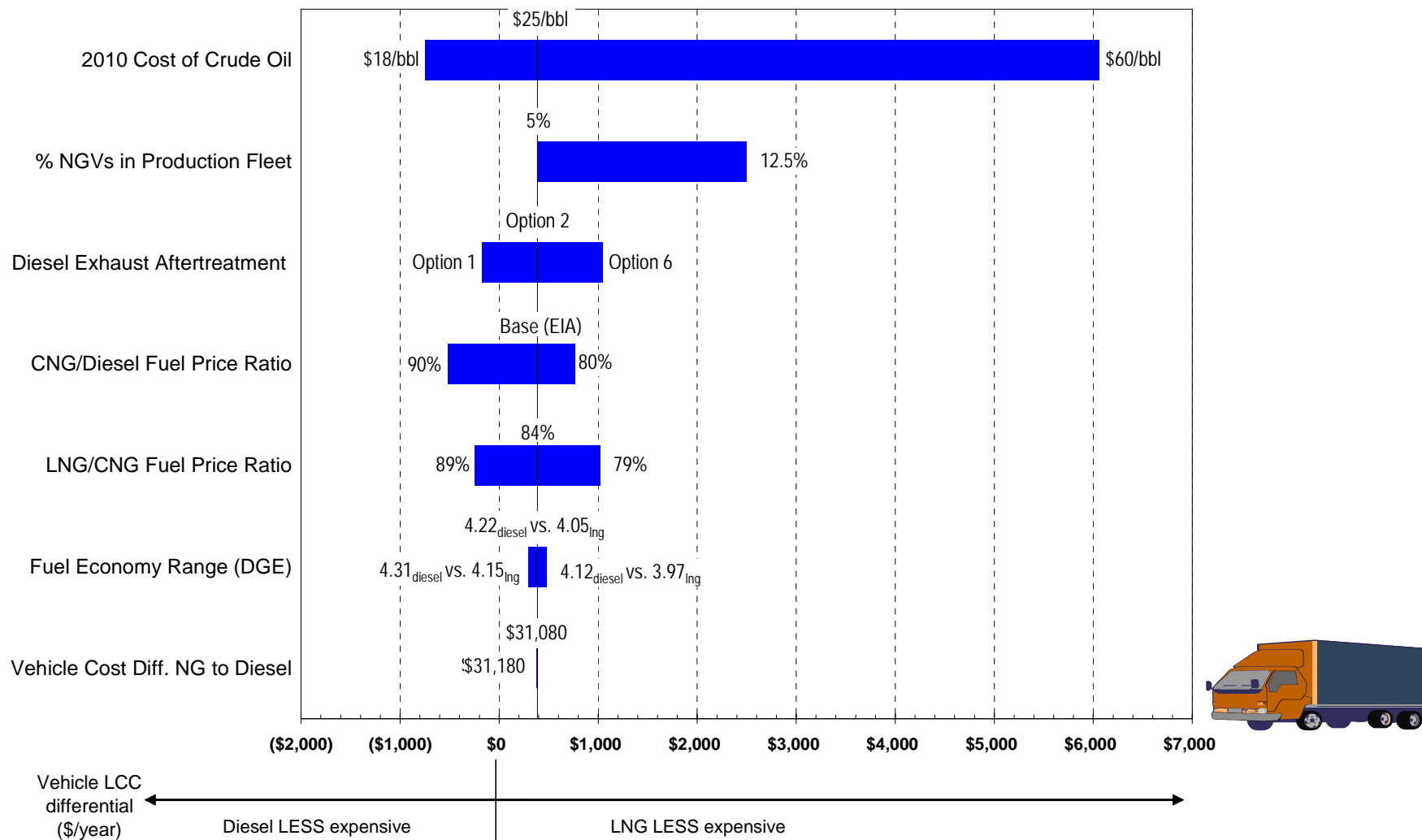
Sensitivity of Refuse Hauler results for LNG compared to CIDI



Sensitivity of Transit Bus results for CNG compared to CIDI



Sensitivity of Short Haul Truck results for LNG compared to HCCI



Crude Oil Price Impacts

- NG vehicles have a price advantage when crude oil reaches a price break-point on an average annual basis. The price break-point is:
 - \$22/bbl for Refuse Hauler
 - \$31/bbl for Transit Bus
 - \$28/bbl for Short Haul Heavy-Duty Truck

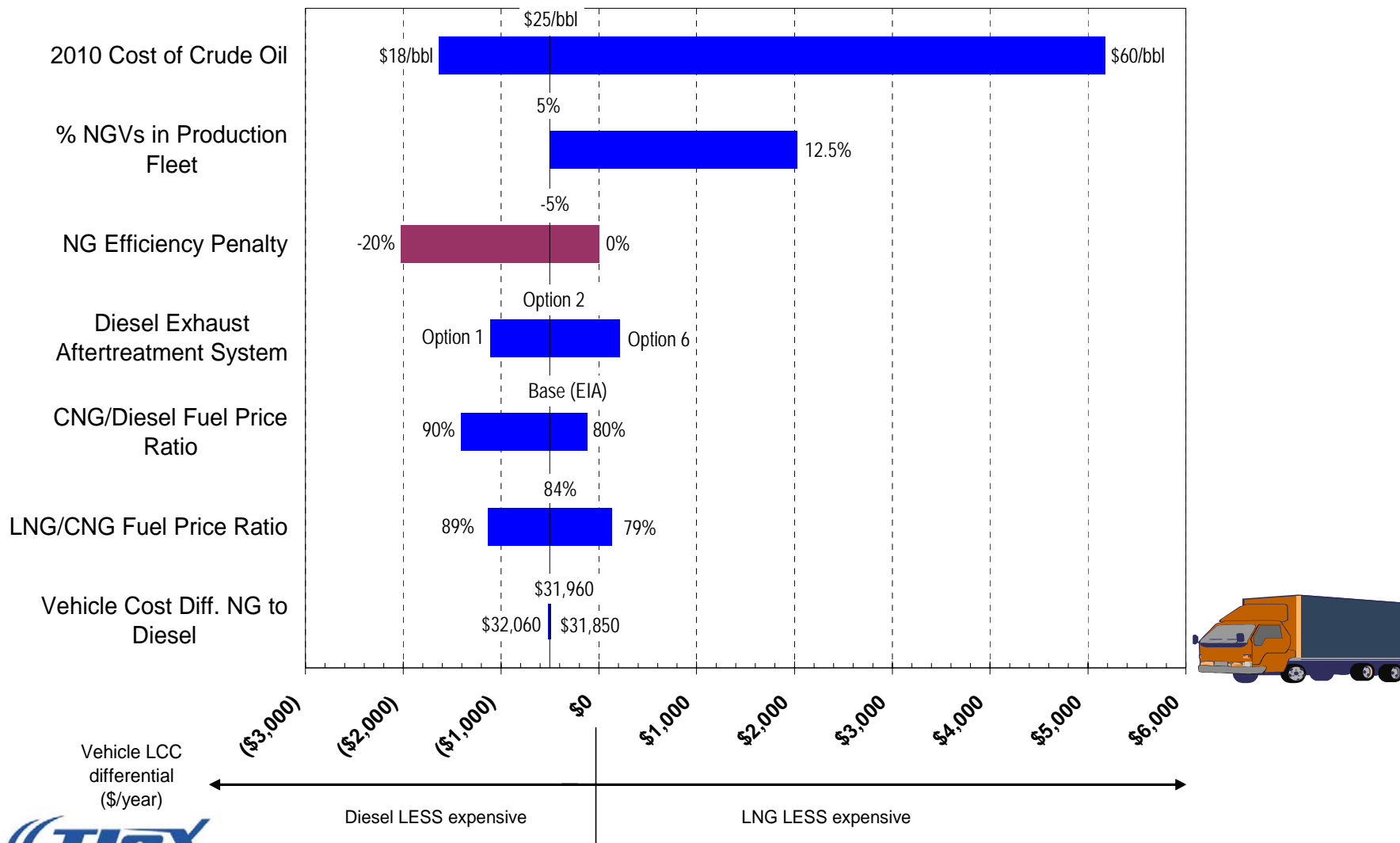
- NG vehicles have a significant advantage over diesel when crude oil is in the \$60/bbl (2005\$) price range on an average annual basis



Additional Sensitivity Parameters

- The cost ranges are based on variation of parameters for different diesel engine technologies in the same vehicle over the same drive cycle (industry average)
- Additional analysis identifies sensitivity of natural gas “engine out” efficiency compared to diesel “engine out” efficiency

For example, the Short Haul Truck AAC is more sensitive to the NG efficiency penalty, then the FE variation over the industry average



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Study Considerations

- Price of natural gas is based on EIA transportation sector delivered fuel and does not include additional station infrastructure
- The study results are predicated on the existence of 2010 natural gas and diesel technologies capable of meeting the stringent 2010 EPA/CARB standards
- Projections of diesel vehicle costs have a higher range of variation because of the uncertainty in diesel engine and aftertreatment systems needed to meet the performance demands of 2010 heavy-duty applications



Summary of results

- 2010 technology natural gas and diesel fueled vehicles are cost competitive with each other over initial owner lifetimes
- Vehicle technology costs for 2010 emissions level diesel vehicles have less price advantage over natural gas vehicles than they do today
- Other than some extreme price scenarios, modeled future costs don't show clear cost preference for one fuel choice over the other in the vehicle applications studied
- The results represent a significant finding, considering the price advantage of diesel over natural gas in meeting 2004 standards.

